Extreme-ultraviolet and X-ray Technology and Training for Interdisciplinary Cooperation

RWTH AACHEN UNIVERSITY

Erasmus Mundus

Exploring the Resolution Limit of the Talbot Lithography with EUV light

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Motivation

The **resolution limit** of the Talbot lithography with extreme ultraviolet (EUV) radiation is explored theoretically. Self-imaging Talbot lithography is a promising candidate for the high resolution printing [1]. Utilizing EUV radiation with wavelength ~11 nm increases the resolution due to the much shorter wavelength in comparison to the conventional UV radiation. As the size of the mask approaches the wavelength level, diffraction influence needs to be evaluated precisely to estimate the achievable resolution and quality of the patterns. We present the results of FDTD simulation of the diffraction on EUV transmission masks in dependence on pitch of the mask, with the aim to determine the resolution that can be realistically achieved with the EUV Talbot lithography.

Introduction and Principle

Talbot effect is a well-known physics phenomenon in which illuminated objects with periodic transmission profile produce self-images [2], [3].

With **monochromatic wave**, a periodic Talbot self-image formed by a line grating with a pitch d appears at distance z_T.

$$z_T = \lambda \Big/ 1 - \sqrt{1-\lambda^2/d^2} \approx 2d^2/\lambda$$

Maximal intensity with period d is observed at intervals $z_T/2$ in propagation direction alternately shifted for half of the period perpendicular to propagation axis.

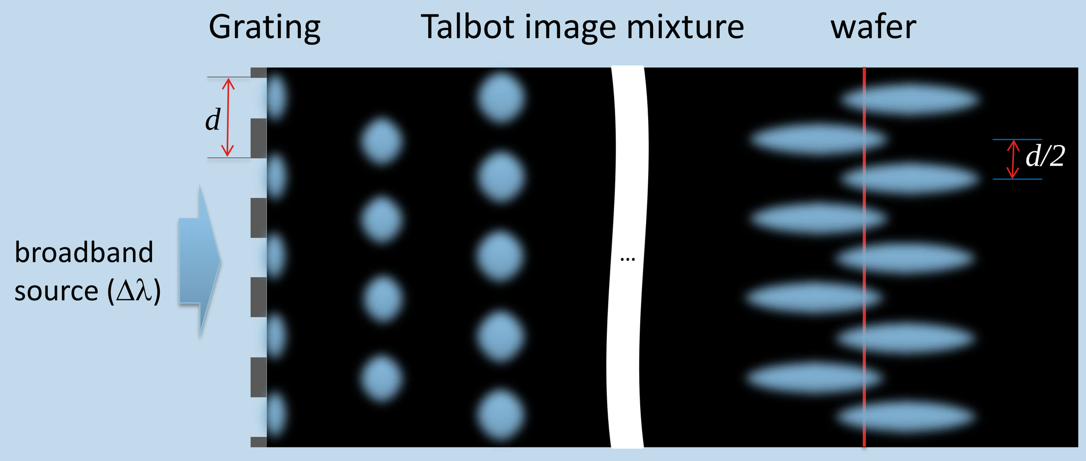
With **broadband spectrum**, Talbot self-images of each wavelength mix in the propagation direction and form a stationary image.

Maximum intensities in x-axis are produced with **half of the period (d/2)** of the grating object at z_M with broadband spectrum.

$\Delta\lambda$: bandwidth

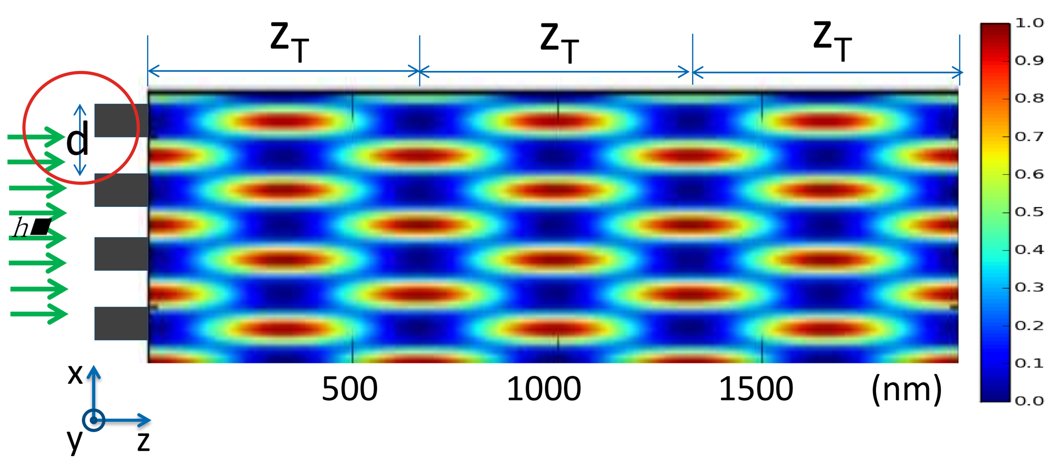
$$z_M = 2d^2/\Delta\lambda$$

Ref. [4]



Talbot self-image with the monochromatic wave

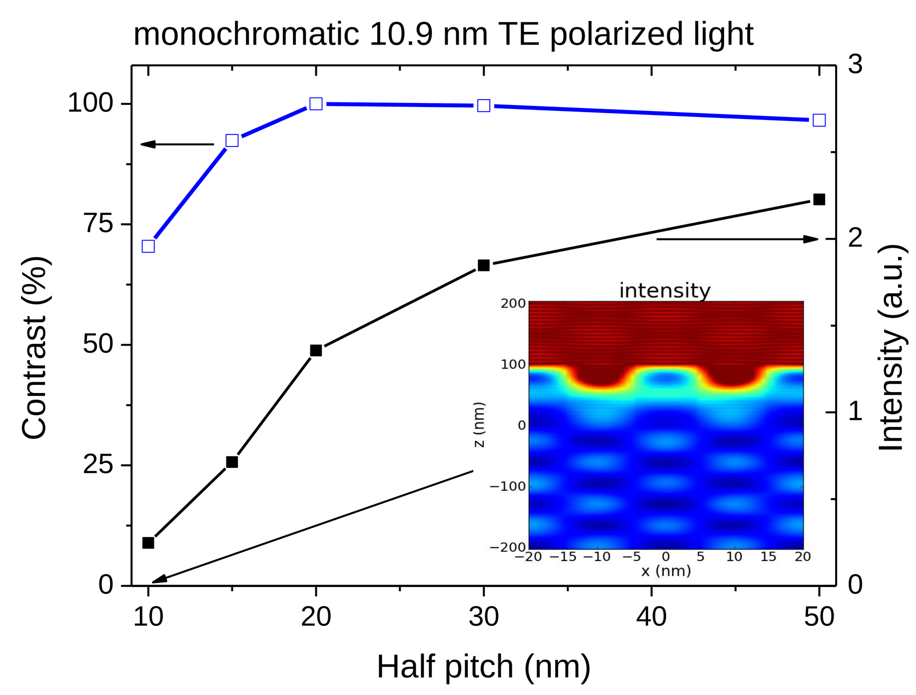
- Wavelength (λ): 10.9 nm
- Grating pitch (d): 60 nm
- Space and line 1:1 ratio



- Talbot self-image repeats with period z_T in monochromatic plane wave.
- First maximal intensities are produced at z_T plane and second maximal intensities are produced at $z_T/2$ plane with d/2 shift in the x-axis.

Dependence of intensity and contrast on pitch size for monochromatic wave

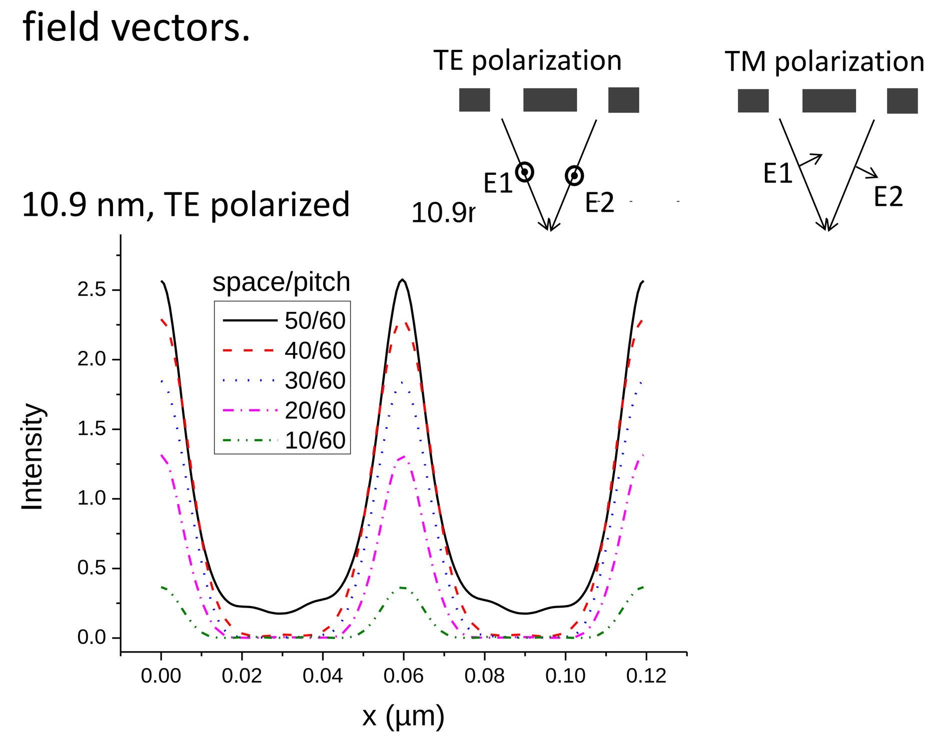
- Grating pitch 20 - 100 nm
- Intensity and contrast are demonstrated for various pitches at $z_T/2$.
- Ni absorber with 100 nm thickness
- Simulated by FDTD method



- Maximal contrast and intensity are decreasing faster below 40 nm pitch.

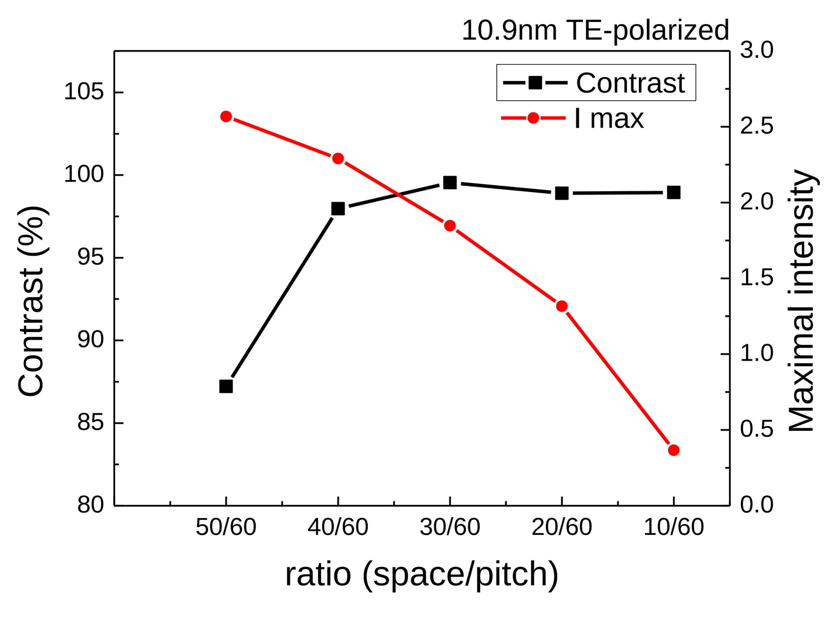
Intensity curves as ratio of space versus pitch in monochromatic wave

- Various spaces (apertures) in 60 nm pitch of grating
- 10.9 nm TE polarized wave
- Ni absorber of 100 nm thickness
- Interference effects are more pronounced with TE-polarized light because of the direction of electric field vectors.



- Maximal intensity at $z_T/2$ is reduced as the space decreases.

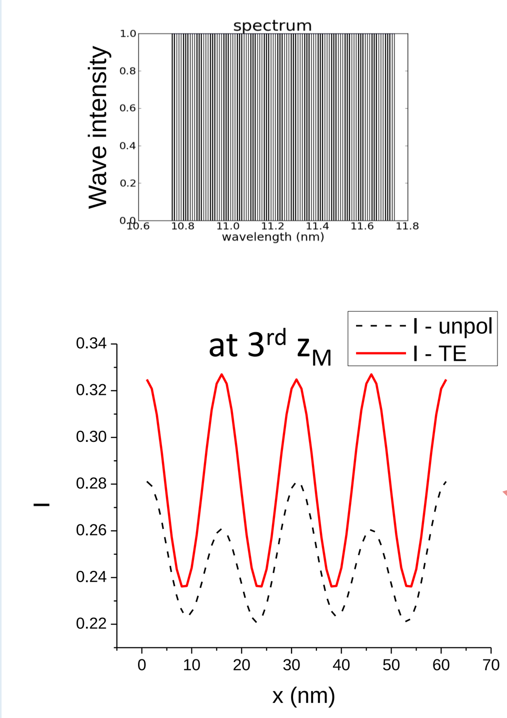
Intensity and contrast versus ratio of space to pitch

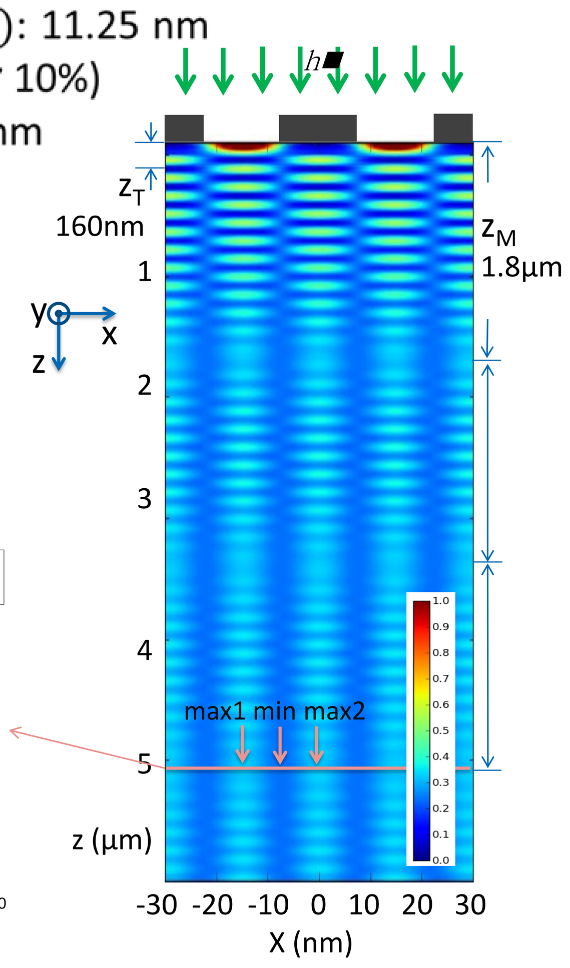


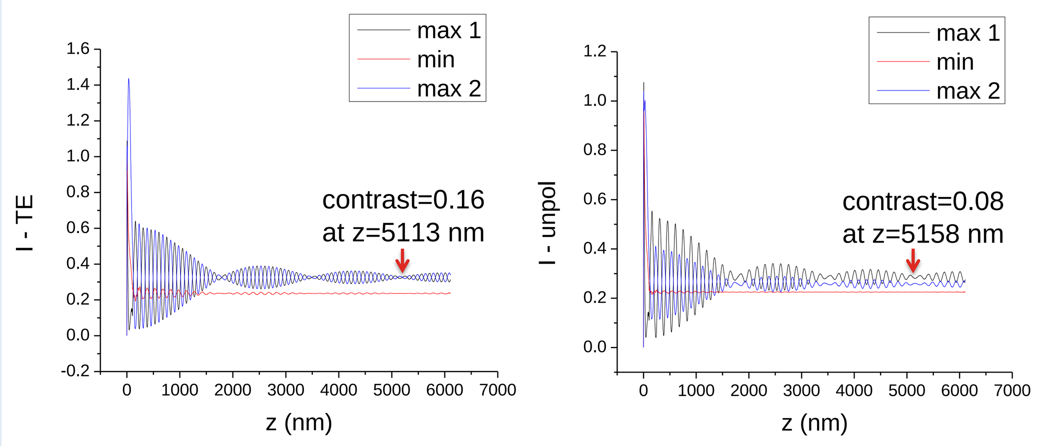
- Maximal intensity drops as the ratio of space to pitch decreases.
- The contrast drops as the space is wider than half of the pitch.
- Best contrast is shown at 1:1 line to space.

Talbot image mixture with broadband spectrum for double self-patterning

- Central wavelength (λ_c): 11.25 nm
- $\Delta\lambda$: 1 nm (bandwidth ~ 10%)
- Grating period (d): 30 nm
- Absorber: Ni (100 nm)

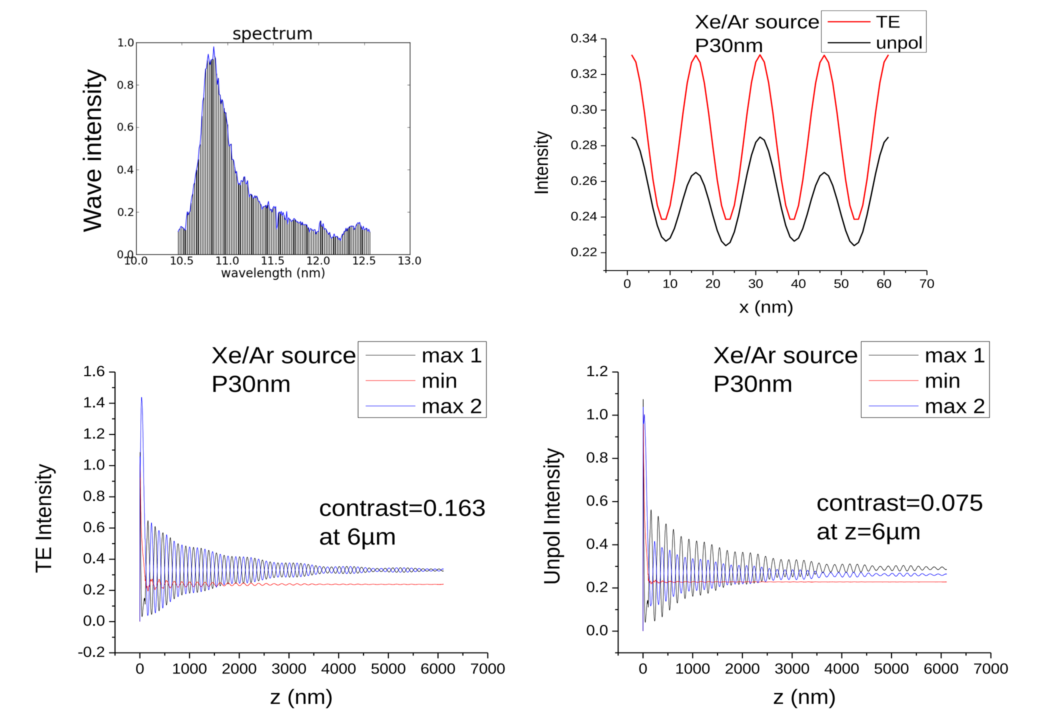






- With the continuous broadband spectrum Talbot self-images mix and form double period at z_M.

Talbot image mixture with Xe/Ar spectrum of EUV discharge source



- Xe/Ar spectrum leads to contrast values comparable to those obtained with the square spectrum shown above.

Summary

- Talbot self-imaging is simulated for the EUV radiation and transmission mask for various conditions, pitch size, space to pitch ratio and polarization.
- Resolution limits for the self-imaging with monochromatic wave and Talbot image mixture with broadband EUV radiation have been explored.
- It is demonstrated that sub-10 nm patterns are theoretically possible but contrast and intensity of the images decrease significantly for patterns with periods below 40 nm in monochromatic wave.
- With broadband spectrum Talbot lithography shows possibility of achieving double resolution in comparison to the grating resolution with Talbot image mixture in a gas discharge source.

[1] K. Patorski, in *Progress in optics XXVII*, edited by E. Wolf, Elsevier Science Publishers, pp. 2-108 (1989)
[2] H. F. Talbot "Facts relating to optical science" No. IV, Philos. Mag. Vol. 9 (1836)
[3] Lord Rayleigh "On copying diffraction gratings and on some phenomenon connected therewith" Philos. Mag. Vol. 11 (1881)
[4] Optics Communications **180**, 199–203 (2000)
[5] Fundamental Principles of Optical Lithography, C, Mack, pp. 110 (2007)